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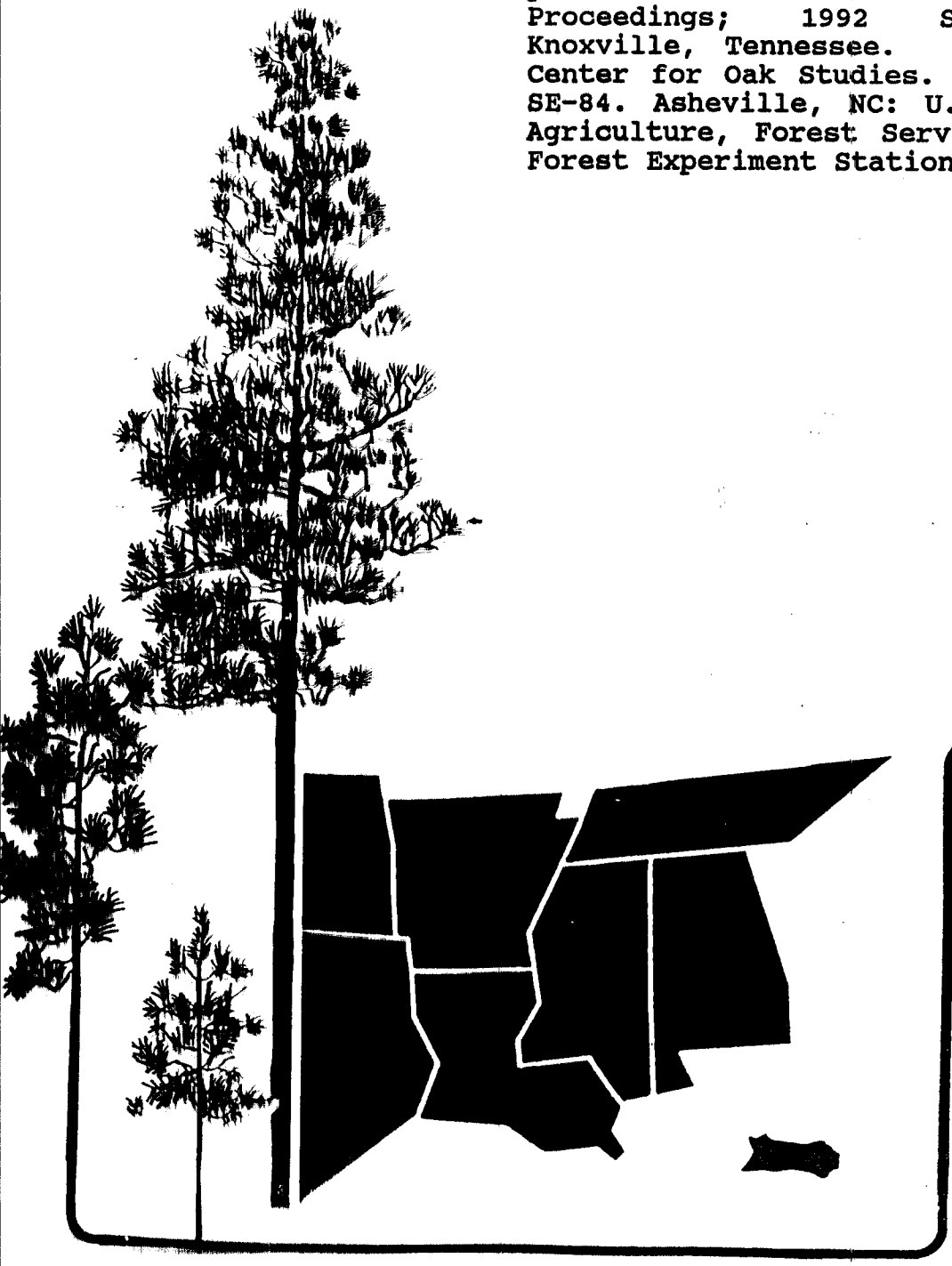

Southern Forest Experiment Station

Oak Plantation Establishment Using Mechanical, Burning, and Herbicide Treatments

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ABSTRACT

Mechanical methods, prescribed burning, and herbicide treatments for establishing oak plantations are reviewed, with emphasis on herbicides. Integrated prescriptions for site preparation using these silvicultural tools are outlined for both clearcut forests and old field sites. The basic premise is that intensive cultural treatments will be required for repeated success in establishing oak plantations using either seeding or planting, when advanced natural regeneration or adequate seed trees are not present. Intensive treatments to promote rapid seedling growth appear critical to minimize the intensity and duration of animal predation on oak regeneration. Labeled herbicides and appropriate application techniques for both woody and herbaceous control are reviewed along with approaches for expanding existing labels and registering new herbicides for oak culture.

INTRODUCTION

Much research attests to the fact that oak plantations probably cannot be established consistently without intensive site preparation, herbaceous weed control, and continued release from invading competitors (Malac and Heeren 1979, Kennedy 1981, Woodrum 1982, Nix 1989). Oak seedlings, like most plants, generally grow better in a competitor-free space, although not always as rapidly as other tree species (Sam and others 1986, Bowersox and McCormick 1987, George and others 1991). Why this is so is not completely clear, but it appears partly due to the slower early growth habit of many oak species, and their propensity to allocate photosynthates into root storage and root growth instead of top growth. There has been ample research demonstrating accelerated early growth of oaks after vegetation control to warrant its use (Aust and others 1985, Krinard and Kennedy 1987, Wendel and Lamson 1987, Miller and Burkhardt 1987, Johnson and others 1989). However, the investment-return outcome for such intensive culture is yet unknown and will remain unknown for some time.

PRINCIPLES OF COMPETITION CONTROL

Over the past decade several principles of vegetation management for plantation establishment have been discovered through extensive research, mainly on conifer species. A summary of these principles that should apply to oak culture includes:

1. Vegetation control can increase tree growth by the greatest proportion in years 1-3, especially when near complete control is achieved around large, healthy

seedlings that have been properly planted, and are not injured by the vegetation control treatments.

2. Early growth gains from years 1-3 are maintained and amplified well into the rotation.

3. Threshold levels of competition reduction must be achieved before a positive growth response occurs, and a point of diminishing returns also exists where additional control gains no further growth response.

4. Plants immediately surrounding crop-tree seedlings are the strongest competitors and should be the main target for control.

5. A mixture of grasses, ferns, forbs, vines, and woody resprouts present severe competition to tree seedlings, but grasses and ferns are the most competitive in the early stages from years 1-5.

6. Woody plants become established in greatest numbers during the first year after clearcut harvesting, while some immigration is continuous.

7. The most severe woody competitors are tree species, not shrubs, that can grow equally with crop trees and maintain a position in the main canopy. Resprouting hardwoods are the most severe woody competitors to planted seedlings.

8. Following mechanical site preparation, woody competition starts exerting its influence in years 5-8, but woody control is most cost-effective prior to planting or in years 1-2.

9. Tree diameters respond proportionally more than heights to competition control.

10. Projected returns on investments in intensive site preparation treatments are usually justified only on sites of medium to high quality unless treatments are necessary to guarantee survival because of management objectives.

Besides competition control, it is known that oak seedlings benefit from soil tillage (both surface and subsoil) with assumed benefits in aiding rapid root development (Plass and Green 1963, Woodrum 1982, Seifert and others 1985, Nix 1989). It is also assumed that site preparation requirements will probably be more stringent for oak seeding than for seedling planting (Bullard and others 1992). It is recognized that these principles and concepts will require further verification for specific oak species as they interact with the multitude of sites and plant community situations.

GENERAL PLANTATION ESTABLISHMENT PRESCRIPTION

A proposed general prescription for oak plantation establishment is that large, healthy seedlings should be properly planted on tilled and appropriately subsoiled sites having minimum hardwood competition, with herbaceous vegetation control treatments applied annually for 2 to 3 years (Malac and Heeren 1979, von Althen 1987). Both woody and herbaceous control treatments must be very effective to realize a return on their investment. Because of the constant immigration of hardwoods into young stands (Cain and Yaussy 1984), woody control treatments should be performed at regular intervals as needed. Hannah (1987) summarized: "The key . . . is to control competing vegetation, keeping the oaks dominant and free to grow." Johnson and others (1989) summarized their understanding: "The abundance of red oak in the herbicide-treated clearcut suggests that the key to regenerating red oak may be competition control and not necessarily a long regeneration period."

Rapid early seedling growth is critical to oak establishment to minimize predation from deer, rabbits, and rodents. Only through enhanced early growth can the time spent in vulnerable stages be shortened. (However, rapid early growth begs the issue of eventual log quality as it is affected by a large juvenile wood core (Maeglin 1987).) At the same time, site preparation treatments must work in concert with the overall management plan and safeguard the multi-resource values of the forest, maintain or improve long-term soil productivity, and protect intrinsic site values.

SITE PREPARATION FOR CLEARCUT SITES

Intensive site preparation treatments on cutover forest sites often require the integrated use of mechanical, burning, and herbicide treatments.

Mechanical Treatments

The advantages of using mechanical site preparation treatments before planting or seeding are numerous. Logging slash can be pushed into piles or windrows using rootraking or processed with choppers or flailers. Rootraking is also used to dislodge woody plant roots, minimizing woody competition and increasing available nutrients and water for crop tree growth (Burger and Pritchett 1988). The clearing of slash then permits other soil amelioration treatments—disking, bedding, and subsoiling.

Morris and Lowery (1988) reviewed site preparation research in the South and concluded that only disking, bedding, and subsoiling are likely to have large positive effects on tree growth. On upland and poorly drained sites, disking has been shown to benefit oak establishment (Woodrum 1982, Seifert and others 1985, Nix 1989). On poorly drained sites, bedding has yielded short-term growth increases that may be maintained (Seifert and others 1985). Disking increases the rootability of the surface soil across the entire area, while bedding does the same and locally raises the soil above the winter water table (Morris and Lowery 1988). However, the volume of tilled soil is less with bedding compared to disking and root closure between rows may not occur as quickly as on disked sites.

The principal disadvantage of rootraking treatments occurs when valuable site nutrients are displaced into windrows and piles, and away from planting rows and seedling access (Morris and others 1983, Tuttle and others 1985). Further, raked or disked organic matter is made to decompose faster, perhaps before seedling roots can take full advantage of the ensuing nutrient release (Banker and others 1983, Miller and Edwards 1985, Burger and Pritchett 1988). Soil disturbance also clears the organic mulch from the soil surface that aids in preventing evaporative moisture loss. At the same time an abundance of herbaceous plants can become established on the bared soil and represent severe early competition. The herbaceous communities also form excellent rodent habitat that encourages seed and seedling predation. On some sites, revegetation after intensive mechanical scarification is slowed or spotty leading to sheet and rill erosion and nutrient loss (Blackburn and Wood 1990). Only through careful and considerate application of mechanical treatments can these adverse effects be minimized or eliminated.

Subsoiling and ripping are increasingly being used for pine establishment in the South after a history of mixed research results as far as improving both survival and growth (Berry 1979, Lantange and Burger 1983, Wittwer and others 1986). Subsoiling can result in both an increase in the amount of soil exploited by tree roots in the first few years and more uniform depth distribution of roots. Less is known about where and how to apply subsoiling than disking and bedding, but the benefits to deep-rooted species on restrictive soils is obvious. It appears that fracturing of dry pans is preferred to shearing of wet restrictive horizons (Parker and Amos 1982).

There is now a 3-in-1 blade plow manufactured by Symonds, an Australian company, that disks, subsoils (two directions by adding a wing to the ripping blade), and beds in one pass. The 3-in-1 plow has already been used operationally to establish oaks successfully in the South. Another mechanical site preparation tool that could be useful in oak establishment is the Bräcke Scarifer (Alm and others 1988). This scarifier makes discontinuous scarified-mounded planting sites across an area at regularly spaced intervals. About 10 percent of the area is scarified. Oak seeds and seedlings could be planted either in the scarified area or somewhere on the mound—edge to center. Because of the versatility of the hitching arrangement on the scarifier, this implement can be worked in both shelterwood stands and clearcut areas. Seeding and herbicide applications can be simultaneously performed during the operation with added attachments.

Resprouting vigor of hardwoods can be decreased significantly by performing felling or shearing operations after the spring growth flush has depleted root reserves (Zedaker and others 1987, McMinn and Nutter 1988). Performing mechanical treatments during the usually drier summer months should also be more efficient and effective. As the intensity of utilization increases in the future, the need for windrowing or piling treatments will probably decrease, while the need for soil tillage treatments may increase to ameliorate soil compaction caused by intensive harvesting operations.

Prescribed Burning

Prescribed burning is commonly used after mechanical and chemical site preparation to further reduce logging slash and improve planter access. Prescribed fire can, with adequate fuel and proper burning conditions (timing), topkill woody plants that are less than 2-3 in. groundline diameter, but can increase the abundance of annual and biennial herbaceous plants (Langdon 1981, Miller 1982, Danielovich and others 1987, Sanders and others 1987, Yeiser 1992). Perennial grass clumps that are also partially consumed regrow with tender shoots, making them more susceptible to herbicide control. It is also known that repeated burns in a stand prior to harvest, spaced over 5 or more years, can reduce the size of woody plants. Fire can also be used after harvest to accomplish the same effect while reducing logging slash. But after harvest, and more so after methods of scarifying site preparation, fuels are discontinuous and ignition may be difficult and more costly with uneven hardwood control.

Soils are not usually degraded by one or more repeated burns, but developing research would suggest that macropores can be filled and porosity lowered with repeated burning of sandy loam soils, resulting in a depression of soil moisture-

holding capacity (Miller and Boyer 1991). Other research has shown that considerable nitrogen, approximately 60 percent of that in the fuel, can be volatilized from the site with a single burn (DeBell and Ralston 1970, Vose and Swank 1992). Long-term inputs of nitrogen from biological fixation and atmospheric inputs may replace the nitrogen lost from fire, but this is not assured (Boring and others 1991).

Herbicide Treatments

Herbicide applications for site preparation before planting oaks can result in the most positive control of woody and herbaceous competition. Modern herbicides are both safe to the applicator and the environment when used according to label instructions (Miller and Mitchell 1988). They can be applied broadcast, to planting rows, or selectively to individual target stems (Newton and Knight 1981, Cantrell 1985, Miller 1987, Miller and Mitchell 1988). It is necessary that the most effective herbicide or tank mix be selected for both the target species on the site and also site constraints. The herbicide(s) should be applied at the most effective time using the correct application procedure.

Soil-active herbicides should be used with a full appreciation of the risk of nontarget plant damage due to residual carryover or application proximity. But it should be recognized that herbicides having both foliar and soil activity are often the most effective. Those herbicides discussed in the following sections are described further in table 1.

Table 1—Herbicides labeled or used for oak culture; manufacturers, active ingredients, and concentrations in formulations

Product	Manufacturer	Active ingredient(s)	Amount of a.i. or a.e. in formulation[1]
AAtrex 4L	Ciba-Geigy	atrazine	4 lb/gal
Access[2]	DowElanco	picloram + triclopyr	1 + 2 lb/gal
Accord and Roundup	Monsanto	glyphosate	4 lb/gal
Arsenal Ac	American Cyanamid	imazapyr	4 lb/gal
Atrazine 4L	Du Pont	atrazine	4 lb/gal
Chopper	American Cyanamid	imazapyr	2 lb/gal
Chopper RTU	American Cyanamid	imazapyr	3.6%
Escort	Du Pont	metsulfuron	60%
Fusilade	ICI	fluazifop	1 lb/gal
Garlon 3A	DowElanco	triclopyr amine	3 lb/gal
Garlon 4	DowElanco	triclopyr ester	4 lb/gal
Oust	Du Pont	sulfometuron	75%
Pathway, Tordon 101R and RTU	DowElanco	2,4-D + picloram	¼ + 1 lb/gal
Princep 4L[3]	Ciba-Geigy	simazine	4 lb/gal
Tordon K[2]	DowElanco	picloram	2 lb/gal
Tordon 101[2]	DowElanco	2,4-D + picloram	½ + 2 lb/gal
Vantage (Poast)	BASF	sethoxydim	1 lb/gal
Weedone 2,4-DP	Union Carbide	2,4-DP amine	4 lb/gal
2,4-D ester	several	2,4-D ester	4 lb/gal

[1] a.i. = active ingredient; a.e. = acid equivalent.

[2] Restricted use herbicides that must be applied by a State certified applicator or permitted private landowner (contact county agent for permit).

[3] Other formulations of simazine are Princep Caliber 90, Princep 4G, and Princep 80W.

Herbicide Labels. The herbicide label is a legal document that specifies on what type of sites and how a herbicide can be applied. Herbicides legally used in forestry must be labeled for "forest sites," or in some instances for "noncrop areas" and "tree farms" when not broadcast for site preparation. In oak establishment, the use of herbicides that do not have one of these site specifications is unlawful and carries a prescribed fine and prison term for violations according to State laws. It is also unlawful to exceed labeled rates and use methods of application not outlined on the label.

Other specifications on a herbicide label, such as crop-tree species and target efficacy, are involved with product performance and manufacturer liability. It may be legal to use a herbicide for oak culture when the label states "for conifer release," but the manufacturer is not liable for poor performance or crop injury. Thus, the discussion of which herbicides are labeled for oak culture is not simple and will have to be qualified in the following discussions. Also, the interpretation of labels may vary by State. The direction and possible avenues of future herbicide development and registration for oak culture will be discussed at the end of this paper.

Timing of Herbicide Applications. Herbicides perform best when applied at times the target plants are most susceptible and/or the crop trees are most resistant to injury (Miller and Bishop 1989). Applying them before or after the correct time reduces or even eliminates their effectiveness and may damage the crop. As far as the most efficient timing of woody control treatments, herbicide applications should only be made after all resprouts have emerged following harvesting, burning, or mechanical disturbance. Woody rootstocks must have sprouts before herbicide activity and control can occur.

Woody Plant Control with Tree Injectors and Backpack Sprayers. The manually applied treatments for woody plant control that should have use for oak establishment are:

- tree injection
- stump sprays
- directed foliar sprays
- basal bark sprays

(Soil spot applications using Velpar L Herbicide by Du Pont appear to have limited use in hardwood culture because of the residual nature of Velpar L.) All sizes of trees and shrubs can be controlled by using the right treatment when the proper herbicide is applied at the correct time. Here are the sizes of woody plants that can be treated most effectively by manual application methods:

Method	Effective size of target stems controlled
Injection	sizes greater than 2 in. d.b.h.
Stump sprays	all sizes
Directed foliar sprays	up to 6 ft. tall
Full basal sprays	up to 6 in. d.b.h.
Streamline basal sprays	up to 2 in. d.b.h.

A combination of methods can be used on the same site when an array of target stem sizes are to be treated. Often, on the same site, tree injection is used for the larger trees, basal or foliar sprays are applied to the smaller woody competitors, and stumps of harvested trees are sprayed.

Tree Injection. Tree injection is the least costly of these herbicide treatments for controlling unwanted trees that are 2 in. in diameter and larger. This method is highly versatile and can be used alone or in combination with other individual stem treatments for site preparation, hardwood release, timber stand improvement, stand conversion, and creating snags for birds and other wildlife. This physically demanding method requires applicators that can repeatedly and precisely chop into tree trunks deep enough to properly deliver herbicide for uptake in the sap flow. Each cut must form a pocket into the sapwood, where the herbicide is placed for uptake. The herbicide should stay in the pocket and not seep out through any split sides, because any herbicide on the bark is wasted. When treating sprouting clumps, each stem must be injected. The variable results that can occur with this method are partially caused by the inability of applicators to penetrate the bark sufficiently or to correctly place the herbicide for uptake.

Common methods of tree injection are:

- tubular tree injectors
- hypo-hatchets
- hack-and-squirt

Tubular tree injectors consist of a long metal tube fitted with a chisel-type blade that is used to cut through the tree bark into the sapwood near the base of the tree. Several models are available. Units are equipped with a lever, handle, or wire that is pulled to deliver the herbicide (usually 1 mL) from the cylinder into the cut. The delivery rate can be adjusted for accurate calibration. To calibrate: fill and prime the injector; pull the handle or wire 10 times while collecting the herbicide in a container graduated in milliliters; if this is not 10 times the desired rate, adjust the lock-nut and repeat the procedure until accurate calibration is achieved. Frequent sharpening and maintenance of injection tools is needed for best results.

The hypo-hatchet consists of a hatchet with an internal herbicide delivery system that is connected by a hose to a herbicide container carried on the back or belt. When the hatchet strikes a tree, the blade must penetrate into the sapwood and the impact drives a piston forward delivering 1 mL of herbicide into the cut. The rate cannot be adjusted. Daily cleaning and lubrication of the impact piston is required maintenance, along with periodic replacement of rubber O-rings and seals. Safety glasses should always be worn when using a hypo-hatchet because of frequent herbicide splashes.

Hack-and-squirt is a method that uses a narrow-bit ax, hatchet, or machete for making the cut, along with a spray or squeeze bottle or oiler to deliver the herbicide. A grinder can be used to narrow the bit of axes and hatchets for easier and better cuts. Most commercial spray bottles are set to deliver 1 mL with each trigger pull, but each must be checked prior to use. Safety glasses also should be worn when using this method. Waist-high injections by the hypo-hatchet and hack-and-squirt methods are just as effective and fast to perform as basal injections.

With larger stems, more herbicide is applied by basal injections because of the larger groundline diameter compared to diameter at breast height.

The amount of herbicide per injection and the edge-to-edge spacing are specified on the herbicide label. Continuous edge-to-edge cuts should be used on hard-to-control species such as dogwood, maple, and hickory. Herbicides labeled for tree injection that have wide control spectrums are:

- Arsenal Ac
- Accord and Roundup
- Chopper
- Garlon 3A
- Pathway, Tordon RTU (Ready To Use), Tordon 101R, and Tordon 101
- 2,4-D

Some of these herbicides have the same active ingredients with new names or a slight difference in formulation (table 1). Accord is the same as Roundup without a surfactant, Chopper is half the concentration of Arsenal Ac, and Pathway is the new name for Tordon RTU and Tordon 101R. Accord will replace Roundup, and Pathway will replace Tordon formulations as the other names are phased out. Efficacy of these herbicides for selected species is presented in table 2.

Table 2—Species susceptibility to injection herbicides under ideal conditions and timing

Herbicide	Susceptible		Moderate	Tolerant
Arsenal Ac/Chopper	Sweetgum	Hickory		Pine
	Southern red oak	Dogwood		Elm
	Northern red oak	Ash		
	White oak	Beech		
	Post oak	Sourwood		
	Water oak	Blackgum		
	Chestnut oak	Red maple		
	Black cherry			
Accord/Roundup	Sweetgum		White oak	Ash
	Southern red oak		Northern red oak	Hickory
	Post oak		Water oak	
	Blackgum		Red maple	
	Sourwood		Black cherry	
			Dogwood	
			Pine	
			Elm	
			Chestnut oak	
			Beech	
Garlon 3A	Sweetgum	Dogwood	Blackgum	
	Southern red oak	Pine	Water oak	
	Northern red oak	Elm	Red maple	
	White oak	Chestnut oak	Black cherry	
	Post oak	Sourwood	Ash	
	Hickory		Beech	

Table 2—Species susceptibility to injection herbicides under ideal conditions and timing—(Continued)

Herbicide	Susceptible		Moderate	Tolerant
Pathway/Tordon	Sweetgum	Beech	Red maple	
	Southern red oak	Hickory		
	Northern red oak	Sourwood		
	White oak	Dogwood		
	Post oak	Pine		
	Water oak	Elm		
	Chestnut oak	Ash		
	Black cherry	Blackgum		
2,4-D	Southern red oak		Sweetgum	Water oak
	White oak		Northern red oak	Red maple
	Post oak		Black cherry	Ash
	Blackgum		Hickory	Chestnut oak
	Dogwood		Pine	Beech
	Elm		Sourwood	

Garlon 3A and Accord (Roundup) have the advantage of no soil activity. Of these two, Garlon 3A is preferred because it is effective on more species, especially maple and hickory. Arsenal Ac, although soil active, has the broadest spectrum of control of any of these herbicides and can be used at wider-spaced injection cuts. Garlon 3A and Arsenal Ac are usually applied diluted at 33-50 percent and 5-10 percent, respectively. All products can be applied year-round, except during times of heavy sap flow in the spring. Arsenal and Chopper are most effective when injected from July to October.

Stump Spraying. Stump resprouting of many species can be prevented or decreased by a low-cost herbicide treatment following harvest and after partial cuts for timber stand improvement. Stumps larger than 12 in. diameter do not usually resprout and do not need treating. Of course, other hardwoods may invade an area with time. Hand clearing treatments for release or thinning can be enhanced by treating the stumps with herbicide. Stump spraying after bush-hogging is another treatment alternative. The same herbicides that are used for injection are labeled for stump treatments; also labeled are Chopper and Chopper RTU that have the same active ingredient as Arsenal Ac.

A backpack sprayer can be used that has a wand or spray gun equipped with a straight stream, fan, or hollow-cone nozzle. A sawyer can carry herbicide in a utility spray bottle for treating stumps after cutting. For small-diameter stumps, a wick applicator can be used.

Freshly cut stumps should be treated as soon as possible. Stump treatments within 4 hours of cutting have been most effective—the sooner the better. For stumps over 3 in. in diameter, the outer edge or cambial area must be completely wetted with the herbicide. Smaller stumps are usually completely wetted. To be successful, all small stumps should be treated. Thus it is best that the sawyer or companion applicator treats soon after felling so no stems are skipped. Cutting and

herbicide treatments can be performed during late winter and summer. Winter treatments are slightly less effective than growing-season treatments, but only a 60-80 percent control success should ever be expected with stump spraying (Zedaker and others 1987). Older cut stumps can be treated with the streamline basal stem mixture (see that section). The mixture is applied to the outer 1 in. edge of the stump until runoff and to the base of any sprouts.

Directed Foliar Sprays. Directed foliar sprays are more cost-effective than basal sprays for controlling woody competition that is less than 6 ft. tall (Thomas and others 1989). Directed foliar sprays are usually applied with a backpack sprayer fitted with a spray wand equipped with a full cone, flat fan, or adjustable cone spray tip. Spray guns attached to the backpack unit with narrow flat-fan tips are also used by some applicators. Backpack mistblowers are another means of applying foliar sprays (Garrett and others 1989). The spray is applied to the target foliage, being sure to cover the growing tips and wetting the leaf surfaces without drip.

Herbicides labeled for directed foliar sprays for site preparation, that are not restricted to "conifer" reforestation, are:

- Accord and Roundup
- Garlon 3A and Garlon 4
- Tordon 101 and Tordon K
- 2,4-D and Weedone 2,4-DP

Tank mixes of these products will usually be more effective when treating mixed species (Johnson 1987; Shiver and others 1990, 1991). The comparative efficacy of most of these products when applied singly as foliar sprays at various timings have been reported, except the Tordons and 2,4-D (Miller 1990b). In general, the most effective timing for most species was found to be from mid- to late-summer. Arsenal Ac was also tested and found to have the most broad-spectrum control, but it is only labeled for conifer site preparation. Care should be exercised that at least 6 months lapses between application and planting when using Tordon.

Basal Sprays. Basal sprays are more costly than directed foliar sprays for controlling the same sized woody plants (Thomas and others 1989), but basal sprays can control trees larger than 6 ft. tall and can be applied in the late dormant season resulting in less unsightly brownout than foliar sprays. Labeled herbicides that have broad-spectrum control are Garlon 4 with no soil activity, and Access, Chopper, and Chopper RTU with soil activity. Chopper RTU is applied undiluted while the other products are mixed with oil and/or a penetrant for bark applications..

Full Basal. Full basal treatments require that the lower 12 to 20 in. of target hardwood stems be completely wetted with the spray mixture on all sides. A backpack sprayer is used with a wand or spray gun fitted with a narrow angle flat fan, cone, or adjustable tip. Herbicides are used that are soluble in oil and mixed at percentages specified on labeled products, usually less than 10 percent.

Streamline Basal. Streamline basal treatments can control many woody plants including hardwoods up to 2 in. d.b.h. (Miller 1990a). Trees of susceptible species

up to 6 in. in diameter can be controlled. Treatment of small hardwoods that are less than 2 in. d.b.h. results in the most control.

To apply this treatment, a backpack sprayer is used with a spray gun and a low-flow (0.1-0.2 gallon per minute (gal/min)) straight-stream spray tip. Also, a narrow-angled tip can be used, such as 15° and 0.1 gal/min. For controlling herbicide output to prevent waste, a pressure regulator is needed to maintain pressure below 30 lb per square inch (lb/in.^{2}). At these pressures, an effective reach of 9 ft. is possible while bark splash is minimized. Sprayers with diaphragm pumps will maintain about 30 lb/in.^{2} with slow, steady pumping.

The most commonly used mixture for streamline application includes Garlon 4 at 20 percent, a penetrant at 10 percent, and a carrier such as diesel fuel or mineral oil. This mixture is clear when made correctly, while a white cloudy liquid or gel will form if even a small amount of water is present. No amount of water should be in the sprayer or mixing container. Make sure that all water has been drained from the sprayer, the pump has been pumped dry, and the sprayer has been rinsed and pumped with mineral oil or diesel before filling with the mixture.

For treating stems that are less than 2 in. d.b.h., apply the stream of spray up-and-down single stems for about 6 to 8 in. or as a 2- to 3-in.-wide band across multiple stems. Direct the spray stream at a point about 6 to 24 in. from the ground to smooth juvenile bark. Stems that are beyond the juvenile stage, thick barked, or near 3 in. in diameter require treatment on both sides, unless they are susceptible species. Back and forth bands can also be sprayed on larger stems.

Applications are usually made in late winter and early spring when leaves do not hinder spraying the stem and the effectiveness for many species is maximum (Pancake and Miller 1990). The best application time will depend on the herbicide, species, and location. Avoid applications on hot days if an ester formulation, such as Garlon 4, is used because crop injury may occur from vapor drift.

Broadcast Applications by Helicopters and Ground Sprayers. Herbicides labeled for broadcast applications prior to planting hardwoods are:

- Accord and Roundup
- Garlon 3A and Garlon 4
- Tordon 101 and Tordon K
- Oust (herbaceous plant control)

The best control will be obtained by using mixtures of these products if there is a mixture of target species on a site (Johnson 1987; Shiver and others 1990, 1991; Seifert 1990a). Oust can also be mixed with these herbicides without decreasing their effectiveness while increasing herbaceous control (Jones and others 1986). However, the most effective mixture for controlling a specific species mix is still up for conjecture, requiring the user to consult local extension specialists and knowledgeable managers. When competition is essentially only one species, then one herbicide may be best. For controlling sugar maple (*Acer saccharum* Marsh.), Garrett and others (1989) reported that Tordon 101 as a 20-percent solution was most effective of the 11 herbicides tested using a mistblower.

These herbicides can be applied by both aerial and ground sprayers. Aerial broadcast applications are commonly used on tracts of 50 acres or more, because of improved coverage and costs compared to ground applications. Professional aerial applicators generally use helicopters with spray systems equipped with microfoil booms, thru-valve booms, raindrop nozzles, or other devices to assure accurate applications with a minimum risk of off-site drift to neighboring lands. Managers should verify the accuracy of calibration before application. Herbicide mixing procedures, especially in batch trucks, should be examined and even tested for thoroughness, which can be performed by using electrical conductivity with Accord mixtures (Lautenschlager and Schaertl 1991). Pumping the mixture three times through the system can also assure adequate mixing. The land manager or owner also has responsibilities for preparing the site for aerial treatment, such as felling tall snags, heliport construction, and marking boundary lines that are visible from the air.

Broadcast site preparation treatments are also conducted with various types of tractor sprayers. Boomless cluster nozzles, manifold nozzles, and mistblowers mounted on either rubber-tired tractors and skidders or track-type tractors are used on sites with flat or gently rolling terrain. Applicators can now use computerized sprayer control systems on their tractors that automatically maintain the proper rate on terrain where ground speeds vary, but these require calibration that should be verified by the manager. For treatment of small regeneration areas, hose-reel sprayers mounted on trucks or tractors are also used.

Broadcast herbicide applications are often followed in 8-12 weeks with a prescribed burn to reduce standing and down woody material for better planter access. Burning does not always increase hardwood control (Minogue and Lauer 1992) and can volatilize site nitrogen, as previously discussed. Chopping is also being increasingly used after herbicide spraying in pine culture, with and without burning, to improve access and the ease of subsequent operations.

Control of Problem Plants During Site Preparation. Some of the problem weeds that can hinder or prevent plantation establishment are hayscented fern (*Dennstaedtia punctilobula* L.), New York fern (*Thelypteris noveboracensis* (L.) Nieuwland), japanese honeysuckle (*Lonicera japonica* Thunb.), kudzu (*Pueraria lobata* (Willd.) Ohwi), trumpetcreeper (*Campsis radicans* (L.) Seemann), grape (*Vitis* spp.), multiflora rose (*Rosa multiflora* Thunb.), privet (*Ligustrum* spp.), and eastern redcedar (*Juniperus virginiana* L.). A summary of herbicides for treatment includes:

Hayscented and New York ferns. Oust alone (1-2 oz/acre) or in a tank-mix with Roundup (1 qt/acre) applied between early July and early October (Horsley 1988, 1990). The timing of Oust for site preparation can influence the damage on other desirable hardwoods (Horsley and others 1992). McCormick and others (1991) in Pennsylvania on poorly drained soils found that fall applications of Oust at 2 and 4 oz/acre alone or in combination with Roundup at 1 qt/acre had no effect on germination of northern red oak (*Quercus rubra* L.), but did increase first-year mortality by 14-16 percent and reduced second-year height growth by 14-23 percent.

Japanese honeysuckle. Escort at 1 oz/acre applied May to August or Roundup at 0.75-percent solution applied September to October (Edwards and Gonzalez 1986, Regeher and Frey 1988, Schmeckpeper and others 1987).

Kudzu. Tordon 101 at 1-2 gal/acre or Tordon K at 0.5-1 gal/acre applied June to September both in year 1 and repeated with half the rate in year 3, with spot clean-up as needed and a 6-month wait before planting after last application (Miller 1988). Eradication on the site is needed before planting.

Trumpetcreeper. Roundup at 4 qt/acre applied July to September (Pyle and Krueger 1984).

Grape. Smith (1974) summarized screening trials and recommended basal bark sprays (lower 12-18 in.) in oil mixtures using 2,4-D ester (many brand names) and Weedone 2,4-DP at labeled rates and cut stump treatments using water mixtures of Tordon 101 (50-percent solution) and Roundup (20-percent solution) and undiluted Pathway (Tordon RTU, 101R), all applied early March or mid-September.

Multiflora rose. Roundup in a 1-percent solution or Garlon 4 in a 0.5-percent solution using summer or winter applications (Bhowmik and Germond 1987).

Privet. Arsenal AC in a 1-percent solution and surfactant sprayed in mid-summer.

Eastern redcedar. This species is not a basal sprouter, so cutting near groundline is effective. For large trees, foliar spray with Tordon K at 0.25-percent solution in a 1-percent diesel oil-water emulsion, wait 3-4 weeks, and ignite crown (Stritzke and others 1991).

These species must be nearly completely controlled or eradicated from a plantation site or the remaining plants will spread quickly.

SITE PREPARATION ON OLD FIELD SITES

The use of disking and subsoiling should be considered for improving soil conditions and competition conditions before planting oaks on abandoned fields and pastures (Malac and Heeren 1979). Disking treatments will improve planting operations if performed correctly and often promote annual herbaceous plants that are more effectively controlled with herbicides than are perennial plants. Disking should be to a depth of 8 in. and should be done in strips along the contour to reduce the chance of soil erosion. Unfortunately, disking can aggravate wet-weather planting the following spring. Subsoiling or ripping can be used to break up plowpans that are common to these sites.

Part of the decision to use tillage treatments must consider whether the site is designated as wetlands and whether the tillage practice would be considered "sod busting" that might jeopardize participation in USDA-sponsored farm programs.

For controlling pasture grasses and/or forbs before planting, late-summer applications of Roundup can be applied broadcast or in bands to form planting

rows. Only Roundup appears specifically labeled for this situation. Rates of 3-5 qt/acre will be required to control established sod, and even then complete control cannot be expected. A prescribed burn in early summer, before the Roundup applications, can clear standing dead grass parts to improve herbicide efficiency. Also, mowing can be used to improve access and allows better spray coverage by reducing vegetation to a more uniform height. If mowing is done before a herbicide treatment, wait for 4-6 in. of weed regrowth before Roundup applications.

HERBACEOUS WEED CONTROL IN YOUNG OAK PLANTATIONS

Erdmann (1967) noted the benefits of herbaceous weed control on red oak establishment in old fields using Princep 4L at 1 gal/acre applied at the time of planting. Disking prior to spraying was found to enhance control. Erdmann, in the same study, and others (von Althen 1972, Wendel 1980, Nix 1989) have reported that black plastic and cardboard mulches are ineffective for herbaceous weed control with oak establishment and can harbor rodents. Erdmann reported that plowing and disking failed to stimulate rapid height growth of oak seedlings, but mechanical site preparation was a prerequisite to satisfactory weed control when using simazine (Princep). For sandy soils, he recommended applying 2-2.5 lb active ingredient/acre, although this use is no longer labeled.

Numerous screening studies have identified Oust, Princep, and Roundup (Accord) to be effective for herbaceous weed control when planting oaks, with the addition of atrazine having inconsistent results (Kosinski and Holt 1985; Wright and Holt 1985; Seifert and Holt 1985; Jones and others 1986; Seifert 1989a, 1989b, 1990b). Crop-tree injury usually increased with increased rates. Several of these studies also showed that Arsenal, as yet not labeled for hardwoods, held promise for herbaceous weed control with minimal oak injury. Seifert (1989b) after testing 11 herbicides/combinations applied for 2 consecutive years in southern Indiana, found that Oust provided the best weed control and least damage to northern red, white (*Q. alba* L.), bur (*Q. macrocarpa* Michx.), and black oak (*Q. velutina* Lam.) when applied at 1, 2, 4, and 8 oz/acre. Subsequent tests found that 4 and 8 oz/acre were too high and could result in stunting and mortality (personal communications with John Seifert). Wright (1986) studied pre-plant spring herbicide applications for site preparation for red and white oak plantings on old fields with forbs, grasses, and semiwoodies and found combinations of Roundup and Princep to be costly but effective while Oust was partially effective but released broomsedge. Unfortunately, resistant species (like broomsedge) or mid-summer annuals often recapture the treated area when effective herbaceous control is achieved, requiring the use of Roundup spot treatments with shielded spraying.

Two greenhouse studies have indicated that Oust inhibits the emergence and principally root growth of northern red oak (Sam and others 1986, Shipman and Prunty 1988), but the height growth of surviving seedlings was significantly increased. Similarly, Barnes and others (1990) have shown that Oust reduces root growth potential of loblolly pine (*Pinus taeda* L.), but it is still widely used for pine release because of eventual growth stimulation through competition control.

Sam and others (1986) found that of the preemergent herbicides tested, only Oust performed equally well on bare soil or forest litter. Therefore, applications to bare soil are not needed with Oust as has been required with Princep applications.

Two herbicides commonly used for establishing hardwoods have questionable registration at this time. In 1987, the use of Princep (simazine) for establishing forest plantations was removed from the label, although the product is still registered for Christmas trees, nurseries, and shelterbelts. Also, the use of atrazine is limited on labels to conifer establishment, which appears to make use in hardwood establishment the responsibility of the user with no recourse for product performance or crop damage. This interpretation may vary by State.

The use of repeated disking or mowing as a substitute for herbicide applications for herbaceous weed control has not been fully tested. Zutter and others (1987) reported that repeated herbicide applications were more effective than repeated cultivation for sweetgum (*Liquidambar styraciflua* L.) and green ash (*Fraxinus pennsylvanica* Michx.), because the inter-row vegetation was not controlled by cultivation. Malac and Heeren (1979) presented plantation establishment guidelines for hardwoods that stressed at least 2 years of frequent disking for competition control. The cultivator disks were designed to cast a mound of soil against the row of trees to smother the weeds within the row. Kennedy (1981) reported that 4 years of repeated cross disking on a clay soil with severe herbaceous competition enhanced diameter growth of Nuttall oak (*Q. nuttallii* Palmer) 240 percent over checks, while repeated mowing was not different from the check. When comparing cultivation with herbicide control, it is recognized that surface evaporation from cultivated soil is greater than from soil covered with herbicide-controlled vegetation acting as a mulch. However, preemergent applications of herbicides, because of their timing, may not result in a mulch of dead vegetation either. Also, the bare ground caused by either cultivation or herbicides will soon be revegetated to some degree.

Herbicides for Herbaceous Weed Control

Oust. At present, Oust is labeled for herbaceous weed control at 1-2 oz/acre after transplanting (not seeding), specifically for northern red oak, white oak, and chestnut oak (*Q. prinus* L.). The lower rate is used on coarse-textured soil. The efficacy of Oust on certain species is presented in table 3.

1. Oust is best applied as a preemergent herbicide (before weeds emerge).
2. Oust is not recommended for use on poorly drained or marshy sites, but it may be used where hardwoods have been planted in beds.
3. Application should be made at the time of tree planting or within 2 weeks of tree planting, in the spring before planted seedlings leaf out.
4. Seedling injury can occur if the planting slit is not fully closed and if bud break has occurred. Injury also can occur if heavy rainfall occurs after application and root growth has started.

Simultaneous seedling planting and spraying can be used with a simple spray attachment to the planting machine. Three years of herbaceous weed control have been recommended for hardwood establishment on old fields in Indiana by Wright and Holt (1985). Even though mixtures of atrazine and simazine have been in use for many years, they are no longer labeled specifically for hardwood establishment.

Table 3—Weed species usually susceptible to preemergent application of Oust at 2 oz active ingredient/acid equivalent

Susceptible	Moderate	Tolerant
Ragweed	Panic grasses	Broomsedge
Fescue	Goldenrod	Bermudagrass
Horseweed	Dogfennel	Nutsedge
Ferns[1]	Bahiagrass	Morningglory
Burnweed	Johnsongrass[1]	Woolly croton
Boneset	Pokeweed	Tropic croton
Sunflower		Trumpetcreeper
Poorjoe		Sicklepod
Dewberry[1]		Cocklebur
Vetch		Lespedeza
Geranium		Wiregrass
Golden weed		Plumegrass
Sweet clover		
Crabgrass		
Brome		

[1] Controlled only partly in preemergent or early postemergent applications to seedling plants, not established perennials.

Fusilade and Vantage (formerly Poast). Two herbicides that can be used for controlling only grasses are Fusilade and Vantage. (Vantage is a ready-to-use, weaker formulation of the herbicide Poast.) They are expensive products to use and both require up to two applications for controlling perennial grasses. Neither control broadleaf forbs or nutsedge. Fusilade is generally considered safe for over-the-top applications on all hardwood and conifer seedlings, while the phytotoxic effects of Vantage are assumed to be the same. Grasses must be small and tender for over-the-top applications. Fusilade is applied at 32-48 oz/acre with a nonionic surfactant and Vantage is applied at 35-61 oz/acre. Both can be applied only by ground application, using label-specified equipment.

Application Methods for Herbaceous Control

Herbaceous weed control can be accomplished using broadcast, band, or planting spot applications. Band applications are possible only when planting rows are well defined and wind conditions permit spraying well-defined bands. Banded or spot applications cost considerably less than broadcast treatments since only a part of the area is treated, while only small losses in pine growth and survival occur when bands or spots exceed 3 ft. in width or diameter relative to broadcast applications (Dougherty and Lowery 1991, Yeiser 1992). However, growth response increases in proportion to the area treated and reinvasion may be quicker with spots and bands (Dougherty and Lowery 1991). Initial growth retardation in the first year due to toxicity by some herbicides is overcome, resulting in a positive growth response by age 2-3 for both oaks and pines (Wright and Holt 1985, Yeiser 1992).

Broadcast applications can be made by backpack sprayers, tractor sprayers, or helicopters (Oust only). Banded treatments are applied using backpack, all-terrain vehicle (ATV), or tractor sprayers. Backpack sprayers treat one row at a time

while machine sprayers can treat two or more rows using a boom with spaced nozzles. Bands usually range from 3 to 6 ft. wide. Precise mixing and application are essential for successful treatments.

To apply banded treatments, the boom or spray wand is fitted with a wide-angle, flat-fan tip, such as 80° or 110°, with flow rates of about 0.2 to 0.3 gal/min or two narrow-angle tips per row. When using a single wide-angle tip per row, a special flat fan tip that is "even" will increase control on the edges, compared to a regular flat fan that applies less herbicide on the edges. Also, flood tips are commonly used for banded applications, because one tip can apply a 3 to 5 ft. band. Wide angle or multiple tips are used to minimize the wind influence by having the tip close to the ground. Tip arrangements should be selected and arranged to assure even distribution across the band while minimizing rates around the planted seeds or seedlings. Thus, two tips can be positioned on either side of the seedling where the overlap is minimal to lessen the rate applied directly to the seedling.

Pressure regulation and a constant nozzle height and ground speed are needed to maintain uniform application rates. Use a pressure of 5 to 15 lb/in.^{2} to give large droplets with reduced drift. The low flow rates from low pressure operation also permit more acreage to be covered per fill-up, adding to the efficiency of the operation. Special "extended range" or "low pressure" tips are designed especially for low-pressure applications. A pressure regulator is necessary to maintain low pressures with backpack sprayers as well. Some backpack sprayers can be set at the desired pressure while others rely on the installation of regulators in line or on the wand.

Many types of sprayers can be modified to apply banded herbaceous weed control treatments in plantations. One increasingly common machine is a four-wheel, ATV equipped with a sprayer. ATV and tractor sprayers can be equipped with sprayer control systems, with ground speed sensing. Sprayer control systems can maintain a constant application rate over a wide range of operating speeds (Miller and Mitchell 1988).

Spot applications must be used when planting rows are not well defined. Spot applications can be made with the above banding procedure using a backpack sprayer with some change. Mainly, the sprayer is turned off between seedlings as the applicator follows the rows. The sprayer is turned on about 1.5 to 2.5 ft. before the seedling and shut off at the same distance past the seedling. Thus the same tips, pressure, and calibration can be used. The applicator must still maintain a constant walking speed while spraying each seedling if the rate is to be constant.

Full cone tips, with flow rates from 0.2 to 0.4 gal/min, can be used to apply circular, tree-centered spots using a backpack sprayer or spotgun. However, full cone tips with these low flow rates produce very fine droplets that are easily blown by wind. An adjustable cone nozzle produces large droplets, but these droplets are too large to ensure uniform coverage of preemergent herbicides. Thus, it is difficult to achieve good results with full cone tips.

RELEASE AND THINNING

Inevitably release treatments will be required in oak plantations as partially controlled woody plants and new immigrants appear. Although research has begun to find effective over-the-top selective release treatments, it may be some time before successful treatments are identified and developed (Pham 1987).

Mixed results for oak release have been reported, but the variable results are probably due to ineffective control and the initial vigor of the released oaks. Wendel and Lamson (1987) concluded that rapid resprouting of cut-only release treatments nullify any benefit. Russell (1974) studied planted northern red oaks treated at 6-7 years in the Cumberland Plateau and found that woody competition clearing, once or continuously for 3 years, showed improved diameter growth, but not height growth after 3 years. Nix and Cox (1987) studied cherrybark oak (*Q. falcata* var. *pagodifolia* Ell.) plantings (2-0) and found that seedlings released in 3-4 ft. radius spots using Roundup directed sprays late in the second year did not grow better than unreleased trees. In a subsequent study, Nix (1989) reported significant release response to the same treatment on the same crop species, but released in the first year. Woodrum (1982) studied cherrybark oak in South Carolina and found that glyphosate release spraying caused decreased height growth (suspected drift) but increased diameter growth in the growing season of treatment.

As summarized in the introduction, diameters are influenced more than heights by competition reduction treatments, as also reported in these release studies. Also, release treatments must be applied at a very early stand age to ensure a response. Release should be applied in year 2 and repeated as needed to control invading arborescent hardwoods. Often, past the second year, the costs of control increase geometrically. Release treatments that treat greater than a 3 to 5 ft. diameter spot around the seedling should also be more effective but obviously will cost more. Sprouting clumps and tree species with rapid juvenile growth should be the primary control targets.

Roundup is the only herbicide that is currently labeled for "postdirected sprays" on "silvicultural sites." A 2-percent solution should be sprayed to cover the foliage of target woody competitors while preventing spray solution on crop foliage. To minimize crop seedling damage, a shield cover can be placed over the nozzle to help prevent drift. Also, applications should only be made during times of low wind. Drift control agents can be added to the spray mixture, but their addition can possibly lessen control effectiveness. Herbicide damage to crop trees can nullify any release response.

Release by directed sprays will only be feasible when target plants are less than 6 ft. tall and are species susceptible to Roundup. Garlon 3A, Garlon 4, and Arsenal AC could legally be used for directed sprays, but since the label specifies such treatments only for conifer release, the user would accept all liabilities of oak seedling damage.

Basal sprays with Garlon 4 in oil carriers can be used for release treatments, but crop-tree damage can occur from volatility when treating on warm days. Thus, winter applications in January and February are preferred. For larger competitors, cutting and stump treatments with Roundup and Garlon 3A are labeled uses, but crop-tree mortality may occur due to root grafts and root exudation and uptake.

Thinning can be important in the production of quality hardwood logs, and thus herbicides may play a critical role for precommercial thinnings and preventing resprouting of commercially thinned oaks. Both directed foliar and basal sprays could be used for precommercial thinnings. The systemic activity of herbicides will have to be tested to identify herbicides suitable for thinning sprouting clumps so as not to injure the selected crop sprout.

FUTURE REGISTRATION OF HERBICIDES FOR HARDWOOD MANAGEMENT

All herbicides used in the United States must be registered by the Environmental Protection Agency (EPA) as specified in the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and its amendments. To develop a new herbicide requires years of extensive scientific testing on the product's chemical properties, efficacy, and mammalian and environmental toxicology, after formulation development has been achieved. Costs of developing, testing, and registering a new herbicide presently exceed $30 million.

A unique requirement for pesticides registered for "forest use" is the environmental fate study, whereby the active ingredient and byproducts (metabolites) are tracked through a watershed application until dissipation below detection limits is documented in plants, soil, and water. This study alone now costs about $500,000 for a single test. Herbicide companies must then plan to recapture this investment plus profit, before embarking on a full "forest use" registration. Obviously, for products with good conifer tolerance and broad-spectrum control, this investment is justified, and over the past 15 years there have been numerous new herbicides registered accordingly. Unfortunately most of these herbicides are for controlling hardwoods, not establishing them.

Some herbicides, such as Fusilade and Vantage, are being used in forestry, especially for hardwood culture, under the categories of "noncrop areas" and "tree farm" without having an environmental fate study. It has been verbally conveyed by EPA that this procedure will be permitted as long as the herbicide is not used for broadcast applications in site preparation. Perhaps other herbicides presently registered for other crops can gain use in hardwood culture in a similar manner.

The registration process offers three other avenues for gaining labeled herbicides required for hardwood culture. First, herbicide companies could be requested to extend their existing forest use registrations of "site preparation herbicides for conifer culture" to include uses in hardwood culture. Tests of the residual activity of site preparation herbicides, like Arsenal Ac, would have to be performed and appropriate waiting periods between application and planting or seeding be specified on the label, to manage the liability risk. Second, shielded applications could be specified for nonselective herbicides for use as hardwood release treatments. This is underway with the Accord label, with promises to have shielded applications specified on the next label edition.

Perhaps the quickest way to gain registration is though the provisions in FIFRA for Special Local Need registration. Under Section 24(c) of FIFRA, a State may register any federally registered pesticide to satisfy special local needs, provided that (1) registration for such use has not previously been denied or canceled by

EPA, and (2) a food tolerance (safe levels in food), if required, has been established for the proposed use. In forestry the food tolerance would not be required. This "24(c)" registration process has been used for forestry herbicides, the most notable being for Oust in Indiana that led to a Federal supplemental label.

Going further back in the development process, some herbicide manufacturers have begun greenhouse screening on woody plants soon after newly synthesized molecules show promise on major crops and weeds. In the recent past, products suitable for forestry were only identified by happenstance during field screenings performed by company researchers in the "specialty products" areas—forestry being one of these. Still, it is most often the responsibility of "minor use" industries and government agency researchers to identify and develop the use of herbicides from those labeled for general agriculture or rights-of-way. Perhaps herbicide manufacturers can in the future be encouraged to identify those test products that demonstrate selectivity among hardwood species during these early screenings. This will probably be the only way that broadcast oak release herbicides can be developed. Of course, specific herbicides will only be developed when hardwood plantings are being made on a sizable enough acreage to justify this intensity of initial screening.

PUTTING IT ALL TOGETHER

Only with effective cultural tools can intensive oak culture become an affordable reality. Much greater research effort is required to develop these tools. Another effort will be required in sharing what works and what does not work—thus the importance of these Proceedings. The tools must be reasonably priced, which means that the market must be large enough for economy of scale in manufacturing, registering, and marketing. This will take time in the early stages as market size grows with continued success as well as good communication of cultural needs to entrepreneurs interested in this market. The implementation of new tools will require an added degree of technical sophistication by managers to be able to use new methods properly, such as modern herbicides. Integrated establishment systems, combining these tools, will need development and testing. The demand for quality oak wood will drive this development, but timely contributions from research, extension, and manufacturing will all be required.

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